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MANUAL OF METHODS
for
FISHERIES RESOURCE SURVEY AND APPRAISAL

Part 5 - Objectives and Basic Methods

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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MFS - Fisheries Resource Survey

MANUAL OF METHODS FOR FISHERIES RESOURCE SURVEY AND APPRAISAL

Part 5: Objectives and Basic Methods

by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1975

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CONTENTS

		Page
1.	GENERAL CONSIDERATIONS OF SURVEY	1
	1.1 Purpose of surveys	1
	1.2 Types of survey	6
2.	IMPLEMENTATION OF GEAR FOR RESOURCE SURVEYS	8
	2.1 Choice of gear for resource surveys	8
	2.2 Statistics and sampling	10
	2.3 Design of surveys	13
	2.4 Recording of data	15
3.	INTERPRETATION AND USE OF SURVEY DATA	16
	3.1 Stock assessment	16
	3.2 Estimation of catch rates	19
	3.3 Estimation of stock abundance and potential yield	20
	3.4 Presentation of results	22
4.	EXAMPLES	23 - 26
5.	ANSWERS TO EXAMPLES	27
6.	READING LIST	28

1. GENERAL CONSIDERATIONS ON SURVEYS

1.1 Purpose of surveys

Fishery surveys include a variety of activities, carried out by biologists, master fishermen and others, with a variety of objectives. Difficulties have often arisen when carrying out, or analysing surveys because of confusion between different objectives. It is therefore essential at the early stage of planning surveys to determine the specific objective (or objectives) to be obtained by the survey in question. To do this it is important to determine the role that the survey work has to play in the general development of the fisheries. If the biologist or other person planning the survey work is to do this well, he should be supplied with adequate guidance by the fisheries administration on what problems are being faced (or are likely to be faced in the future) by the fisheries, and how it is expected that survey results will help to resolve these problems. It must also be remembered that, like most research activities, survey data tend to prove their value over a period, and that for some purposes it is only survey data extending over possibly several years that can give clear answers (e.g., on the extent of year-to-year fluctuations, or changes in fish stock abundance following changes in the amount of fishing). Although survey programmes will have to be modified from time to time to take account of changing national programmes and priorities, survey work will be most effective if a sustained long-term plan can be drawn up and maintained with as few changes as possible.

All marine fisheries are subject to the same basic constraints, and thus the same basic problems tend to recur, regardless of the area, species or type of gear used. All exploited natural stocks of fish are limited in extent, so that no more than some limited catch can be taken, however much fishing is done. Indeed, for some stocks, increasing fishing will actually lead to a reduction in total catch. The relation between the amount of fishing and the average catch for most stocks of fish is similar to that shown in Figure 1. As a result nearly all fisheries tend to develop through the same stages (see Figure 2). These stages in the development of most fisheries may be classified as follows:

(i) Unknown. Areas or types of fish stocks about which little is known, even regarding the species of fish that might be present. For example, the deep water bottom fauna (which may include shrimps and cephalopods as well as fish of possible commercial interest) along the Indian Ocean coasts of Java and Sumatra may be placed in this category.

(ii) Undeveloped. Catches and fishing effort are negligible. Resource studies are needed to attract the investment to move the fisheries into the next phase.

(iii) Growth. Catches and the amount of fishing are increasing rapidly. At the beginning of this stage the abundance is high, as is the catch per unit effort, which may even increase slightly when fishing starts as the fishermen learn the best seasons and fishing grounds, and the most suitable fishing methods. Thereafter catch per unit effort declines. The net economic returns from the fishery also initially increase rapidly, but with the declining catch rates they reach a maximum and then decline. This in turn leads to a stabilisation of the fishing effort. Where the demand for the fish species concerned is not restricted, this stabilisation will occur somewhere at or beyond the shoulder of the curve in Figure 1. That is the catch taken will be fairly close to the limit set by the potential of the resource, though the amount of fishing used to take this catch can vary. Figure 1 shows two possible equilibrium positions - A, for low-value species, or species for which the costs of fishing are high (e.g., fish that are widely dispersed), and B for high value or low-cost stocks. Unless demand is limited, fisheries on the growth phase will at some time - usually sooner rather than later -

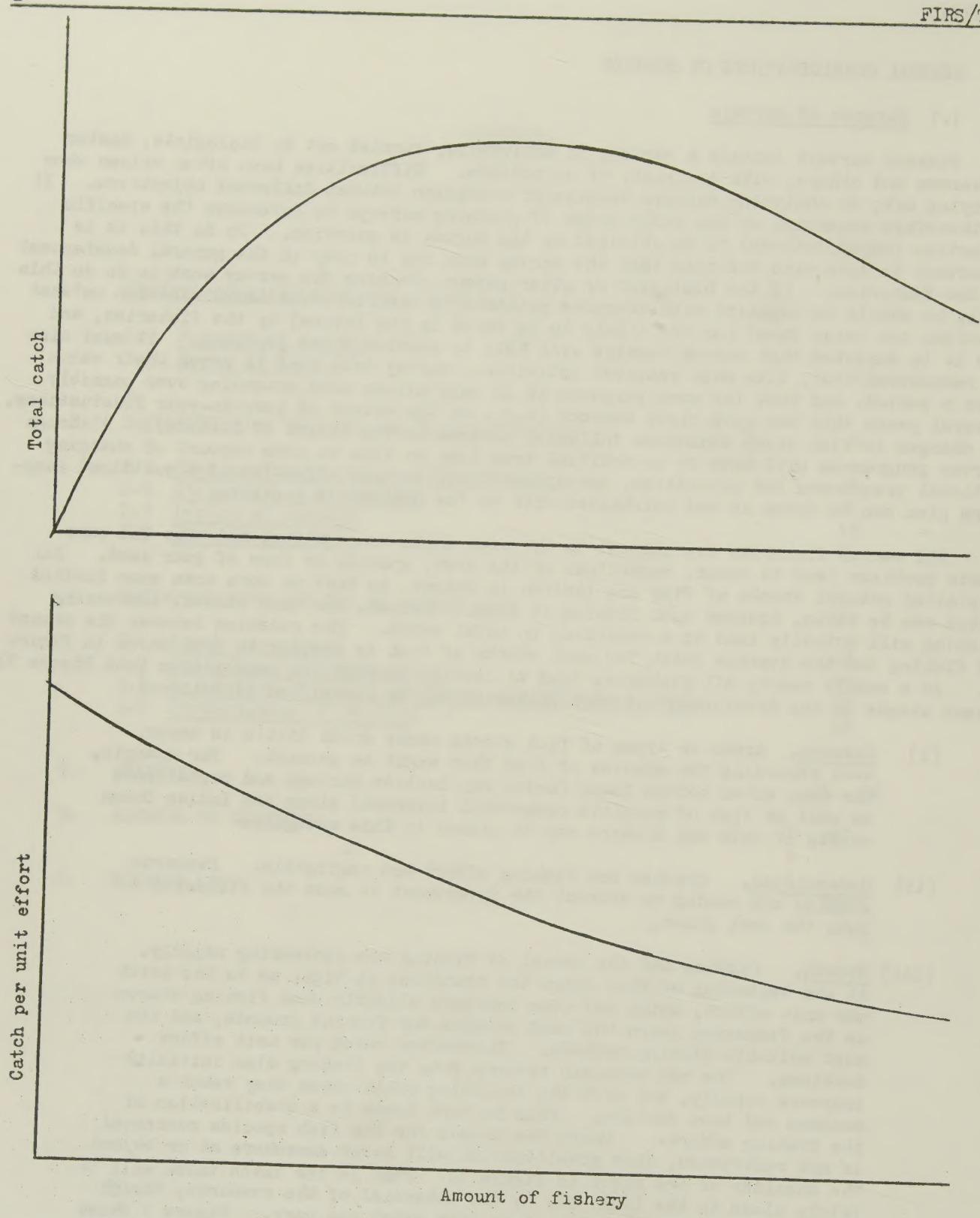
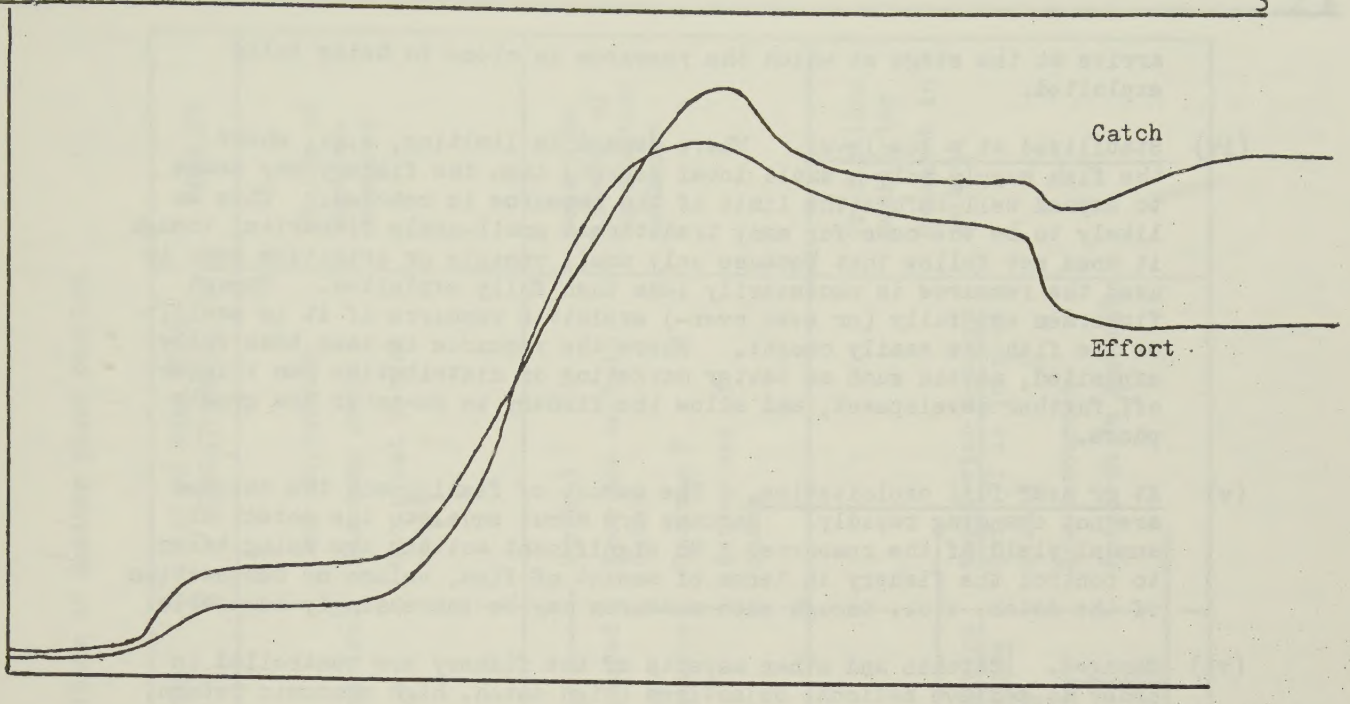


Figure 1: Typical relations between the amount of fishery and the total catch (above), and the catch per unit effort (below)



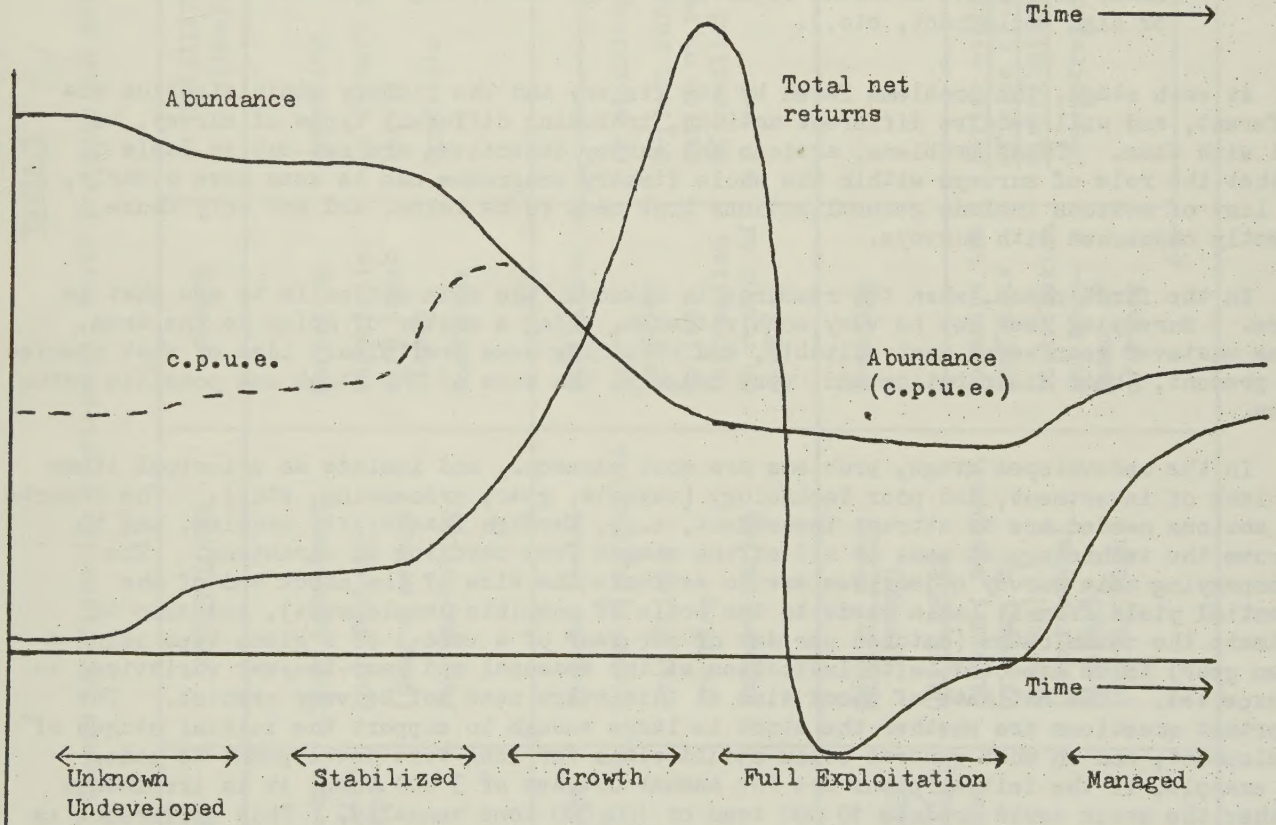


Figure 2: Stages of development of a typical fishery, sharing (upper figure) changes in the total effort and total catch, and (lower figure) in abundance (or catch per unit effort) and total net returns to the fishermen, i.e., total value of catch less total costs.

arrive at the stage at which the resource is close to being fully exploited.

(iv) Stabilized at a low level. Where demand is limiting, e.g., where the fish supply only a small local market, then the fishery may cease to expand well before the limit of the resource is reached. This is likely to be the case for many traditional small-scale fisheries, though it does not follow that because only small vessels or primitive gear is used the resource is necessarily less than fully exploited. Enough fishermen can fully (or even over-) exploit a resource if it is small, or the fish are easily caught. Where the resource is less than fully exploited, action such as better marketing or distribution can trigger off further development, and allow the fishery to re-enter the growth phase.

(v) At or near full exploitation. The amount of fishing and the catches are not changing rapidly. Catches are about equal to the potential annual yield of the resource. No significant actions are being taken to control the fishery in terms of amount of fish, volume or composition of the catch, etc., though such measures may be increasingly desirable.

(vi) Managed. Catches and other aspects of the fishery are controlled in order to achieve national objectives (high catch, high economic return, or high employment, etc.).

At each stage, the problems faced by the fishery and the fishery administration are different, and will require different actions, including different types of survey, to deal with them. These problems, actions and survey objectives are set out in Table 1. So that the role of surveys within the whole fishery programme can be seen more clearly, the list of actions include general actions that need to be taken, and not only those directly concerned with surveys.

In the first phase, when the resource is unknown, the main action is to see what is there. Surveying need not be very sophisticated, being a matter of going to the area, using whatever gear seems most suitable, and obtaining some preliminary idea of what species are present, their distribution and, very roughly, the size of the stock and possible catch rates.

In the undeveloped stage, problems are most numerous, and include as principal items the lack of investment, and poor technology (vessels, gear, processing, etc.). The important actions needed are to attract investment, e.g., through feasibility studies, and to improve the technology at some or all of the stages from catching to marketing. The accompanying main survey objectives are to estimate the size of the stock and of the potential yield from it (as a guide to the scale of possible development), and also to estimate the catch rates (catches per day or per year of a vessel of a given type using a given gear) to be expected, with indication of the seasonal and year-to-year variations to be expected. The estimate of stock size at this stage need not be very precise. The important questions are whether the stock is large enough to support the initial stages of development, and on what general scale should plans for long-term development be made. For example, if the initial plans are for annual catches of 3 000 tons, it is irrelevant whether the stock could produce 10 000 tons or 100 000 tons annually. This difference is of interest for long-term planning, though the difference between, say, 100 000 tons and 150 000 tons is at this stage irrelevant - the fishery is clearly potentially important and it is worth putting a lot of effort, including survey work, into promoting its development.

Higher precision is required of the estimates of catch rates, particularly when they are to be incorporated in feasibility studies, since a small difference in catches can make a big difference to the success or failure of a planned investment when costs and returns are closely balanced.

Table 1

Phases and fisheries development, their problems and methods of meeting phase problem

	UNKNOWN	UNDEVELOPED	GROWTH	STABILIZED (Low)	AT OR NEAR FULL EXPLOITATION	MANAGED
PROBLEMS	No knowledge of what fish are present	Poor investment Poor fishing (Gear & method) Poor Marketing	Marketing Especially with trash fishes Conflicts	Marketing Is fishery at low level? Conflicts	Over investment Too many gears Too great vessel costs	Choice of suitable measures
ACTIONS	Go and look (resource survey	Promote invest Feasibility studies Gear trials Training Improve market	Statistics Catch sampling Collect information on reason of conflict	As at undeveloped Collect information on reasons of conflict	Control Know how much to catch Optimum F Better use of catch	Determine effects of alternative measures
SURVEY OBJECTIVES	Species composition Distribution Rough catch rate	Size of stock (rough) Catch rates (Annual, seasonal, by gear, by species); (experimental fishing); (supply fish)	Training To solve the conflicts Distribution and abundance of of stock	Better estimation of size of stock distribution Demonstration	Monitoring surveys (if c/f is in poor state) New resources Research in general	Predictions monitoring Research in general

In addition to these two major objectives (rough estimates of stock size and rather more precise estimates of catch rates), survey vessels may also be useful in providing samples of fish for initial trials of different processing and marketing methods, and for experimental fishing - that is the testing and improvement of different types of fishing gear. Since these are not survey activities in the sense generally used here, they are put in brackets in the table.

During the growth phase, immediate problems are few. Generally, once development has started, the fishery will continue to grow under its own momentum without external assistance, until limitation of resources (or in some cases limitation of local markets) cause the growth to slow down or stop. At the same time because of these limitations the growth phase cannot continue indefinitely, and once growth slows down problems will arise. The effective solutions to many of these problems often require that appropriate action, particularly the collection of the basic data for stock assessment, is started early and not delayed until the growth phase is coming to an end, and the problems become fully apparent. These requirements are indicated in the table by arrows extending back from the later phases.

When the fishery has stabilized at a level that is (or is believed to be) well below the potential of the resource, most of the problems, and the survey and other actions required, are similar to those of an undeveloped fishery. In addition it is usually necessary to be sure whether or not the resource can support increased exploitation, and there are often actual or potential conflicts between different groups of fishermen who may be exploiting the same stocks. The resolution of both these questions can be helped by surveys aimed at determining the abundance, and particularly the distribution of the stocks concerned, as well as the collection and analysis of suitable data from the fishery itself.

When the fishery is exploiting the resource at or near its full potential, many problems are likely to occur. These are mostly the well-known problems of too heavy exploitation - too many vessels and fishermen pursuing too few fish, with resulting falls in catch rates (and sometimes in total catch), poor economic returns, etc. The main action is to take appropriate management measures (which will be easier if the groundwork for them, and possibly some initial measures such as regulations allowing limitations on the number of vessels, are introduced during the growth phase), but these require detailed information on the state of the resource. This is often best obtained from the activities of the fishery itself, but if effort data is poor, it may be best to monitor the changes in stock abundance by means of regular surveys.

Once the fishery is managed many problems will, almost by definition, be solved. Among the remaining problems an important item is the setting of the detailed measures (e.g., the level of catch quotas) for each season in accordance with variations (due to fishing or natural causes) in the fish stock. These may require special monitoring surveys of the commercial sizes of fish if the catch and effort statistics from the commercial fleet cannot be used to do this, e.g., because these data cannot provide early enough information to take action. Surveys may also be needed to provide prediction of changes in stocks, e.g., by surveys of young fish below commercial sizes.

1.2 Types of survey

Many types of activity have been on occasion considered as survey work, including most sea-going activities. Some of these, e.g., training, or collection of fish for marketing or processing trials, are clearly not surveys in any strict sense, but can sometimes be combined with surveys, e.g., training vessels can use acoustic instruments when covering a pre-arranged track, or catches in trawl surveys can be used in marketing trials.

Two other activities are more related to surveys, but are not considered here. These are (using the definitions of Alverson, 1971):

"Fisheries scouting: the use of research or commercial vessels to locate concentration of commercial fish and disseminate such information to the commercial fishing fleet.

Experimental fishing: activities designed to explore the utility of various types of gear or fishing strategy to increase the efficiency of the extractive phase of a particular fishery."

The major types of survey considered here are:

(a) resource appraisal surveys: surveys designed to provide estimates of the abundance and distribution of a resource, and of the magnitude of the potential annual yield from it;

(b) monitoring surveys: studies on the year-to-year and long-term changes in the abundance or distribution of a stock;

(c) prospecting surveys: surveys to provide estimates of the likely catch rates to be expected, using particular types of vessels or gear.

Both appraisal and prospecting surveys fall within the definition of exploratory surveys in the sense of Alverson, but the difference is important.

Prospecting surveys are directed primarily by a master fisherman. Their objective is to determine the catch rate, e.g., the catches that could be taken by an individual vessel (usually a vessel of similar type to the survey vessel, and using similar gear), per unit time (per year or per day). A particular concern is, of course, whether these catches are above or below the rate which would give profitable return to the type of vessel in question. In general such surveys are only carried out once, and are only repeated in a particular area to determine if there are important season or year to year changes.

Resource appraisal surveys are directed primarily by a biologist. Their objective is to determine the distribution and abundance of the total stock. The results may be expressed as the total biomass of the stock, in tons, which may be further analysed to give estimates of the possible annual yield, again in tons. Such surveys may often use commercial types of gear, but may use other types of fishing gear, or methods that do not involve fish capture.

Though different, these surveys are clearly related, and results of one can give some qualitative information (but usually not quantitative information) for the other type. For example, if high catch rates are observed from prospecting surveys over a wide area, the resource concerned is large, and conversely a large resource is likely to give high catch rates - though a moderate size resource spread over a wide area may not ever be sufficiently concentrated to give more than rather poor catch rates. The important difference lies in how the positions for making observations (e.g., a trawl haul) are selected, and what the catch from that haul is taken to represent. The catch made during a resource appraisal survey will usually be used to estimate the density (e.g., weight of fish per hectare) at the position of the haul, which is then assumed to be representative of the density of fish in the region as a whole, or some specific part of the region (e.g., a particular depth zone). For this assumption to be sound, the position of the haul should be randomly chosen (or chosen in some pre-determined and unbiased way) from the whole or part of the region. To enable accurate comparisons to be made from area to area, or from year to year, it is important that the way that the gear is rigged and used should not be changed.

In a prospecting survey, on the other hand, the catch during a particular haul is usually taken to represent what would be taken by good fishermen working in the area. The precise point at which fishing is done will therefore be chosen taking account of whatever

signs the masterfisherman uses to find a good spot - nature of the bottom, currents, bird flocks, etc. The density at this spot can be expected to be considerably higher than the average density in the region as a whole. Using the catches to estimate the abundance of the resource would therefore give estimates that could be seriously biased. Similarly, during a prospecting survey the master fishermen should be allowed to modify the gear if he thinks this is necessary to work efficiently in the area, since commercial fishermen would also want to do the same. This can still give valid comparisons of catch rates between different areas, though the comparison would not be valid for resource studies.

A lack of recognition of these differences has been the cause of much frustration. At sea the crew of the survey vessel are often unhappy at the low catches that are likely to be taken when carrying out a grid as part of a resource survey, and keep pressing for more fishing to be done where they know (or believe) there are more fish. More seriously, all too often data of survey catches cannot be used because it is not known how the work had been planned - catches cannot be used for resource estimation because positions might not have been at random, and could therefore be biased upwards and equally they give no more than a lower limit to possible commercial catch rates because the positions might have been randomly chosen. Most of this frustration can be removed by clear planning and instructions before each survey, as to what type of survey is to be done, and how the fishing positions should be chosen. It is, of course, possible to do both types of survey during the same voyage, provided the two operations are kept distinct. For example, during a two-week cruise the first ten days may be spent carrying out a grid of predetermined stations to provide resource data. The last four days can then be spent fishing at the most promising spots to provide prospecting (catch rate) data.

2. IMPLEMENTATION OF SURVEYS

2.1 Choice of gear for resource surveys

Resource appraisal surveys, in simple terms, consist of measuring the density of fish (in absolute or relative terms) in a certain sampling area. On the assumption that the density of fish in this area is equal to that in the whole survey region (or a part of it), the abundance can be estimated by multiplying the density in the sampled position by the area of the whole region. The sample area may be a continuous strip (e.g., the volume under the ship covered by an echo-sounder), or a set of individual areas (e.g., the ground covered by a series of trawl hauls).

It is difficult to measure the density or abundance of fish, even in a limited area. No survey or counting technique exists at present which will give a good measure of density for all types of fish under all conditions. A choice has therefore to be made between different survey gears. This choice will depend on the type of fish to be surveyed, the accuracy required, the speed with which answers are needed, and the facilities (especially ship time) that are available.

The methods that can be used include direct counts of the fish (e.g., visual surveys), indirect counts (e.g., acoustic methods), catching non-commercial sizes of fish (e.g., plankton surveys), and catching commercial sizes of fish by various types of normal fishing gear. The advantages and disadvantages of the different methods are examined below.

A. Visual methods: includes sightings from aircraft or ships, and various types of remote sensing.

Advantages: A large area can be covered very quickly, especially from the air. An experienced observer can give good estimates of shoal size, species, and likely catch rates.

Disadvantages: Only applicable for species that come close to the surface for an appreciable proportion of the time. The proportion of the stock counted can vary greatly with time of day and season, but useful annual indices of abundance may be obtained.

B. Acoustic methods: includes vertical echo-sounding, with or without advanced equipment to count returned signals and to measure their strength; also includes sonar (signals sent and received horizontally, or away from the vertical).

Advantages: A large area can be covered quickly. With good equipment and favourable conditions measures of absolute abundance can be obtained.

Disadvantages: Fish close to the bottom, or very close to surface cannot be surveyed adequately. Additional information, usually from fishing is required to identify the species being surveyed. The total population of fish surveyed may differ from the fishable population because of difference in the sizes or species included. Acoustic surveys may count small, non-marketable fish, especially of species giving strong echoes,or under-represent marketable fish of species giving poor echoes, e.g. mackerel.

C. Plankton surveys: usually of eggs or very young larvae.

Advantages: Egg surveys provide estimates that are unbiased by possible avoidance of the gear by the fish. Where the taxonomy of eggs and larvae is known provides species identification.

Disadvantages: Slow and costly, especially if surveys are carried out purely for fishery purposes. Information refers only to the distribution and abundance of adults at the time of spawning, and not to other stages.

D. Fishing surveys: includes the use of all types of fishing gear; may often be combined with acoustic surveys.

Advantages: Provides immediate information on species of fish, and also samples for biologists (e.g., investigation of the size or age of fish, feeding, etc.) or for technologists (e.g., the quality of the fish for different types of processing). May also provide data useful for other purposes, e.g., on likely catch rates by commercial fishermen.

Disadvantages: Can take a long time to cover a wide area. Data difficult to use quantitatively to give an estimate of density because either (a) the area sampled by the gear is known, but the proportion of fish in this area which are caught is difficult to estimate (e.g., bottom trawl), or (b) the area sampled is unknown (e.g., long-lines, traps).

For prospecting surveys the choice of gear is much more limited. When doing these surveys the interest is in estimating what catch rates commercial vessels could achieve (in terms of catch per day, or catch per year) if they were working in the area. It is therefore almost essential that the survey ship uses very similar gear to that which it is expected that the commercial vessels will use. It is also desirable that the ship will have reasonably similar characteristics to the expected commercial vessels. Some extrapolation can be done - for example, catch rates by a survey trawler can be adjusted to allow for different size or engine power from the commercial vessels - but the extent of extrapolation should not be too large, or it is likely to be unreliable, and also not to be treated with confidence by banks or other institutions interested in the catch rates as a guide to possible loans.

The actual gear used in any types of survey must depend on the types of fish to be surveyed. This is most obvious in the case of fishing gears (especially for prospecting surveys), many of which are highly selective for particular species, or even for particular sizes of that species. These restrictions have to be accepted, and the survey has to be directed towards certain species or group of species. It is therefore usually misleading to consider that an area is being surveyed for fish; it is true only that it is surveyed for particular types of fish, i.e., those able to be caught or detected by the types of survey gear being used. While obvious, this point is sometimes forgotten. There are many examples of important resources (e.g., sand-eels in the North Sea) being overlooked for a long time in areas which are well known, and in which it had been commonly supposed that no significant unknown resources existed.

Surveys need not be restricted to a single gear. A combination of gears can overcome the weaknesses of each. Acoustic surveys can be conveniently combined with some fishing methods (probably either purse-seining or mid-water trawling) which can at least be used to identify the species of fish. Often the catch records can be used to quantify the records in respect either of standing stock, or of possible catch rates. For example, the acoustic records may show that, on the average, a school of fish of a certain size (or better) is detected twice a day. If fishing on some of these schools give average catches of 1 ton, then (with due allowance for time spent fishing, rather than looking for fish) catch rates of around 2 tons per day can be expected.

A combination of acoustic methods and some type of fishing appears to provide a system of surveying which will give good results (for both resource appraisal and prospecting) when applied to the smaller pelagic fish, e.g., sardines, or mackerel provided these fish do not keep too close to the surface, or too deep or scattered to be readily detected by the acoustic gear. Also bottom trawling seems to be highly suitable for surveying those bottom-living fish which keep too close to the bottom to be easily detected by acoustic gear, provided they live on a bottom that is not too rough for trawling.

Between them these two survey systems (bottom trawling, or acoustic plus pelagic fishing) can cover a large proportion of the stocks of fish which support important commercial fisheries. One or other system, or the two together can be expected to provide the bulk of any surveys that are carried out. However, there are a number of types of fish stocks which will not be adequately surveyed by either of these methods. These may include resources quite unfamiliar to commercial fishermen, but also include important present-day resources including bottom fish on rough, untrawlable grounds (especially coral reefs) and larger fas swimming pelagic fish distributed over very large areas that do not form readily detectable schools, e.g., tuna.

2.2 Statistics and sampling

Some knowledge of statistics is essential in planning of surveys so that the time and money available is used in the most effective way, and in interpreting the results. Statistical studies are concerned with the characteristics of individuals belonging to a certain population. In this sense a population can have a wide meaning, to include any collection, or group such as the population consisting of all trawl hauls that have been made on the Java Sea. The characteristic of interest might be the weight caught in each haul. The population may be unlimited, e.g., the population of all trawl hauls that might be made in the Java Sea, or definite and limited, e.g., the areas of approximately 1 square mile obtained by dividing the Java Sea along lines of one minute of latitude and longitude.

Individuals will have different characteristics, e.g., the catch per haul, or the numbers of fish in a one square mile may vary. This variation may be illustrated most completely by frequency distribution or histogram showing the frequency with which, for example, catch rates of between 70 and 80 kg per hour occur. Most of the features of a typical frequency distribution can be described by two elements, the central position, and

the extent of the spread each side of the central value. The actual measures used for these are normally the mean, m, and the variance (or standard deviation). These are given by

$$m = \frac{1}{N} \sum_{i}^{N} x_i$$

$$\text{and variance } S^2 = \frac{1}{N} \sum_{i} (x_i - m)^2$$

where N = number of individuals in the population.

Sampling consists of taking a number of individuals from the whole population and examining their characteristics, e.g., making a number of trawl hauls, and measuring the catch rates. If the samples are well taken, their characteristics will be similar to those of the population as a whole. In particular we can estimate the mean and variance of the population as

$$\bar{x} = \frac{1}{n} \sum_{}^{n} x_i$$

$$\text{and } s^2 = \frac{1}{n-1} \sum_{}^{n} (x_i - \bar{x})^2$$

where n = number in the sample.
Note that because the sample mean $\bar{x}$ is used instead of the (unknown) population mean, m, the sum of squares is less than it should be, and to avoid bias we divide by n-1.

It may also be noted that the sample itself is one individual in the population of all possible similar samples, e.g., the population of groups of 20 trawl hauls in the Java Sea. Any characteristic of this population, e.g., the mean, will have its own frequency distribution, with mean and variance. This distribution is important because it shows the degree to which the sample mean can safely be used as an estimate of the population mean, e.g., how well the average catch of 20 hauls represents the average catch rate over the whole of the Java Sea.

If the sampling is good, the mean of $\bar{x}$ will be the same as the population m. Unfortunately the sampling is not always good, so that the two means will differ. The extent of the difference is referred to as the bias. Good sampling to avoid bias is important because the existence of bias is difficult to detect in later analysis. If bias exists, the means of repeated samples may fall close together, and suggest that each sample is reliable, whereas they are only reliable in being in error to roughly the same extent.

The variance of the sample mean will be related to the population variance. If the sampling is simple, and certain assumptions are met (basically that the characteristics of the individuals in the sample are independent) then the relation is

$$\text{Variance of } \bar{x} = \frac{1}{n} \times \text{population variance}$$

$$= S^2/n.$$

$$\text{and standard deviation of } \bar{x} = S/\sqrt{n}.$$

This knowledge of the variance of the sample mean, $\bar{x}$, enables statements to be made about the range within which the true mean, m, probably lies. If the mean and variance

of a distribution is known, then (for a given shape of distribution) the probability of the value for a particular individual differing by a given amount from the population mean can be determined. If this probability is sufficiently small it can be considered unlikely that the individual belongs to distribution, i.e., it belongs to another distribution that is significantly (in the statistical sense) different from the distribution originally considered. What level of probability is considered significant is a matter of choice, but a common choice is 5%, which corresponds to a difference from the mean of twice the standard deviation.

Another way of looking at this in relation to sampling is that there is only a 5% probability (one chance in twenty), of the sample mean differing from the true mean by as much as twice the standard deviation of the sample mean, i.e., the probable limits of the true mean (assuming the sample is unbiased) are

$$\bar{x} \pm 2. \quad S/\sqrt{n}.$$

This expression can be used to determine how many observations (e.g., trawl hauls) need to be taken to estimate the mean (e.g., the average catch per haul) with a given precision. For example, if one would like to know the mean within a% (i.e., have an estimate that has only one chance in twenty of differing from the true mean by more than a%), then

$$2 \quad S/\sqrt{n} = x. \quad a/100$$

or

$$n = \frac{(200S)^2}{ax}$$

It may be noted that for increasing precision (i.e., decreasing a), the number of observations required increases by the square. This means that, beyond a certain limit it is extremely time-consuming to increase precision merely by increasing the size of the sample (see Example 1).

All the foregoing discussion, and indeed all sampling theory, depends on the samples being properly taken. If this is not done it is unlikely that the sample will be representative of the population being sampled, and quite wrong answers can result. Ideally the sample should be a so-called random sample. This means a sample chosen in a properly organized manner, so that each individual in the population has a predetermined chance of appearing in the sample. (In the simplest scheme all individual have the same chance). Failing this, if some individuals are more likely to appear in the sample, their probability of appearing should not be related to the characteristics being studied. For example, it is not unreasonable to make a line of survey stations along lines of latitude (or longitude) of exact numbers of degrees. Though not random sampling it seems unlikely that these positions will have, for example, higher fish densities than areas not on exact degrees. On the other hand taking a few fish to measure from a pile of fish on deck is also non-random, but highly dangerous, because most people, if doing this without other instruction, will pick the larger fish to measure. This will give a highly biased sample.

Picking a sample from a large population at random, or in such a way that risk of bias is avoided, can be difficult. There are two common procedures, stratified sampling, and multi-stage sampling (or sub-sampling), that simplify matters, and can reduce the chance of error or has, and increase the accuracy from a given amount of sampling.

In stratified sampling the whole population is divided into a number of distinct sub-populations. Each sub-population (or stratum) is then sampled individually, and analysis carried out on each, adding the results together to get the estimate for the population as a whole. For example in trawl surveys the area could be divided into a number of depth zones (see Example 5(iii)) or other sub-areas. In addition to simplifying the sampling procedure stratified sampling can give substantially better precision (reduced variance) for a given total amount of sampling. The conditions for this to be possible is that the variance within strata is less than the variance for the population as a whole. This will

nearly always be the case, and the difference can be large with suitable choice of strata, e.g., for bottom trawl surveys consideration should be given to bottom type, depth, etc., in choosing areas - which must be done before the main survey is started.

Mathematically, if surveys of mean density, d, are being made to estimate the total abundance N, over an area of extent A, then, for unstratified sampling

$$\text{variance } N = \frac{A^2 S^2}{n}$$

when n is the number of samples

S^2 is the variance of individual estimates of density denoting A_i, n_i, S_i the corresponding estimates for stratified sampling,

$$N = \sum A_i \bar{d}_i$$

$$\text{variance } A = \sum \frac{A_i^2 S_i^2}{n_i}$$

The variance will be further reduced by careful allocation of the total number of samples n between the strata. It will be least if n_i is proportional to $A_i S_i$, though small differences from this optimum (for statistical purposes) allocation will not matter much (see Example 5 (iv)).

In multi-stage sampling we consider that for example each fish in the ordinary ladnings that might be chosen for measuring will probably be in a box; each box will be one of several landed at the same place on a particular day; and landings will occur at a number of landing places on each of a large number of days. The sampling procedure is to go along this chain, starting with the population of all landing places for the whole year. From this certain places and days are chosen for sampling. At each sampled place/day, certain ships are sampled; from each ship's catch one or more boxes are sampled, and from this box, certain fish are sampled. At each stage the sampling procedure should avoid risk of bias, and in the last stage this is commonly done by measuring all the fish in the box, if this is not too large (e.g., not more than a hundred). This avoids the bias likely to occur by unconscious selection by men measuring the fish in only part of the box. Analysis of this system goes through the same stages, in the opposite direction - from the numbers of a given length in the box, the numbers in the sampled ship may be calculated; from the number on the sampled ship the numbers in all ships landing the same day and so on. This required the calculation and use of a succession of raising factors - the ratio of, for example, the weight (or number of boxes) sampled to the total weight caught by the sampled ship; the ratio of catch of that ship (plus the catch of any other sampled ship) to the total catch of all ships, etc. It is therefore most important that careful records are kept of all these quantities so that the sample data can be properly used (see Example 2).

2.3 Design of surveys

After the objective (or objectives) of the survey is known, and the gear to be used is chosen, it is necessary to draw up plans for the actual survey work. The first step in doing this is to determine the scale on which the work will be carried out. This will require a balance between the restrictions of the amount of money, ships and people that could be available and the desires to have very precise answers in terms of say estimation of stock abundance.

Ideally those requiring information from surveys (e.g., in development planning) would specify the precision needed as well as the type of information required - e.g., ask for estimation of the catch per day of a 100 ton trawler, with confidence limits of $\pm$ 10%.

The volume of survey work to achieve this precision could then be fairly closely determined. In practice requirements cannot be specified so closely, and the choice of the extent of survey work has to be somewhat subjective. The best result is probably achieved by a series of steps - a first estimate of available inputs (e.g., that a ship might be available for eight months), estimation of the degree of precision likely to be achieved with these inputs, consideration of whether this precision is acceptable (or even more than adequate) and possibly adjusting the inputs. One important conclusion that can arise from this is that below a certain level of input a survey of the type being considered cannot provide answers that are sufficiently accurate to be useful. This means that, if sufficient inputs cannot be allocated to the survey, plans for the survey should be shelved until more inputs become available.

Given certain inputs for a survey, a general plan can be drawn up to make the best use of them, using proper statistical techniques, and also taking into account practical operational constraints. This first step will, if the survey area is at all large, be to divide it into sub-areas, each small enough to be surveyed in a single cruise of the survey vessel. Within each sub-area, further sub-divisions (e.g., according to depth, distance from the coast, type of bottom, etc.) can be made, and the usual statistical techniques of stratified sampling applied.

A distinction in design can be made between surveys which are made continuously as the vessel moves (e.g., acoustic surveys) in which the sample is a strip along the ship's track, and those consisting of individual observations, e.g., trawl hauls. Continuous observations will usually be made along a regular grid which can be laid out before the ship goes to sea. This will often, but not necessarily be rectangular (e.g., either north/south and east/west, or parallel and at right angles to the coast). If this is set up with starting points and intervals between lines that are chosen without reference to the stocks (e.g., along exact degrees of latitude and longitude), and are modified only for navigational reasons (e.g., shoals and reefs), then it will satisfy the conditions for proper random sampling. Care should be taken when there are other departures from the pre-determined grid; for example, when an acoustic survey is interrupted to carry out test fishing, or perhaps to investigate flocks of birds seen to one side of the track. These will add to the information collected, but the density of fish during these diversions will tend to be distinctly higher than in the survey area as a whole. The data must therefore be analysed separately, and careful records kept of when travel along the pre-determined track was interrupted, and when it was resumed.

The time taken for a grid survey can be readily estimated, making allowance for the activities other than steaming along the track, that need to be done. For a simple rectangular area of length L, and width W, the time taken, if there is a distance d between adjacent legs of the grid, can be determined by the relation.

$$V \times t_1 \times t_2 = L + W \times \frac{L}{d}$$

where V = speed of ship

t_1 = number of hours per day spent steaming (probably around 16 for an acoustic survey, the other 8 being spent fishing and making other observations)

t_2 = duration of cruise in days

The sampling pattern for individual observations, e.g., trawl hauls, could be determined by choosing each position, within each depth zone or other stratification that may be used, from sets of random numbers (e.g., Mackett, 1973) and this best ensures that the sampling is not biased and is generally reliable. If the number of stations is not small, this can be a laborious process, and requires a complicated and time consuming track of the vessel to visit each station. The work of the master of the vessel and others can be made much simpler if the stations are arranged along the same pattern of grid as used for continuous surveys, at pre-determined intervals (systematic sampling). These may be different when

crossing different stratifications that require different sampling intensities. For example, if fish are scarce below 100 m depth, stations may be made at 20 mile intervals, and at 10 mile intervals in shallower waters.

2.4 Recording of data

For any survey it is most important that full observations are made during the survey and are properly recorded so that the results can be easily used afterwards. Since survey data may be used some years after they were collected by someone who did not take part in the original survey work, the records must be clear in themselves, without the need to rely on memory.

The precise details of the records kept are likely to vary, so that it is not possible to set out in detail the forms for recording data that can be used for all surveys. Experience as the work progresses is likely to make modifications necessary in forms designed at the beginning of the work. It may therefore not always be desirable to start with a whole set of printed forms - though once it is clear what forms are needed, printed forms make recording much simpler. It is, however, essential that before the survey ship goes to sea for the first time there is a clear system of what data should be recorded, in what form, and who should be responsible for making the records or ensuring that they are made. This will almost certainly involve some types of form. As soon as it is clear that a suitable system has been found, including modifications to the original forms and instructions, then printed forms should be introduced.

The types of forms and records that are needed include most or all of the following:

1. Standing instructions or manual of operations. Applicable to all of a series of surveys or cruises. Maintained by the director of the survey programme.

2.(a) Summary of cruise information (cruise plan; cruise report; track chart; listing of all relevant data records). Maintained by the scientist in charge of the particular voyage.

3.(a) Ship's logbook. Continuous record of course, position and other major navigational and operational information. One for each voyage. Maintained by captain/officer-on-watch.

4.(a) Acoustic logbook (where acoustic observations are a major part of the survey). Continuous record of equipment used and echo-traces and other observations. Maintained by cruise leader/scientist on duty.

5.(a) Station record or log. Record of each time the ship is stopped to make scientific or other observations, with information on position, weather, gear used, etc. Maintained by cruise leader/scientist on duty.

6.(b) Catch record. Information on the catches (by species or species groups) made at each station at which fishing was done. Maintained by scientist on duty.

7.(b) Oceanographic record. Information on detected observations made at any station at which more than very simple oceanographic observations (e.g., surface temperature) are made. Maintained by scientist on duty or oceanographic specialist. Similar records may be kept when advanced plankton or other work is done during the cruise.

8.(c) Sampling record. Records of more detailed biological information (especially length measurements, but also data on sex, maturity, weight, etc.) collected from the catches. Maintained by scientist on duty.

Notes (a) One record (book or sheet) per cruise
(b) One record per station
(c) One record per station for each species sampled.

Since the entries in these records are the main direct output of survey work, which even with small ships is very expensive, these are very valuable pieces of paper. They should be carefully catalogued and stored, to ensure that they are not mislaid; the records of what data exist (item 2 above) and the system of storage should also ensure that the original observations are not changed or modified.

Examples of forms that have been used in various surveys are attached. None of these are necessarily ideal for a new survey under conditions different from those of the survey for which they were designed, but they have proved their usefulness for at least one specific situation, and do provide useful guides for the forms to be used elsewhere. Certain features are common to all forms - particularly (i) an initial part that identifies the source of the information (e.g., the name of the vessel, date and position of the observation), (ii) other background information (e.g., type of gear used), and (iii) the basic observations themselves (e.g., weight of fish caught). The identification is important, particularly when data are recorded on loose sheets, which may be misplaced. Without proper identification misplaced data can become virtually useless.

The detailed layout of the forms should be done to make life easy for the person making the initial records - may be a sea-sick scientist in the middle of the night - and the person transferring the data to other records, e.g., punched cards. A well-designed form should make it automatic that all required data are in fact entered in the form.

3. INTERPRETATION AND USE OF SURVEY DATA

3.1 Stock assessment

Stock assessment, i.e., the work of determining the magnitude of fish stocks, the effect of fishing on them, and predicting the changes in catch and stock abundance that would result from changes in the amount or pattern of fishing, is a large subject that covers much more than survey work. The general subject is discussed in much more detail elsewhere (for example, in the FAO Stock Assessment Manual), but certain ways in which survey data are especially useful in stock assessment studies may be noted here.

Two general methods have been commonly used in stock assessment studies - the analytic models and the surplus production models. The first, generally associated with the work of Ricker, Beverton and Holt, consider the fate of the individual fish. By combining the growth in weight of the individuals, the rates at which they die due to fishing or to natural causes, and the numbers of young fish entering the fishing, the catches and stock size can be calculated. Survey data are not generally used in this approach.

The other model, originally associated with the work of Schaefer, considers the natural rate of growth of the population as a whole. This will be small for low populations, and for lightly exploited populations which are large and close to the limited carrying capacity of the environment. At some intermediate population size, the rate of growth will be a maximum. If the catch is equal to this natural growth in the stock, the stock will not change, and this catch can be maintained indefinitely. The catch that can be taken in a steady state, without changing the population, is therefore related to the population. In the simplest case this relation is:

$$C = aP\ [\overline{P(max)} - \underline{P}] \qquad (1)$$

where C = Catch

P = Population abundance

$P(max)$ = Maximum population abundance, when there is no fishing.

In practice it is more convenient to consider the catch as related to the amount of fishing (e.g. the fishing effort, f) rather than the population size. Since the catch per unit effort (c/f) should be proportional to the population, if the measure of effort is well chosen, it is possible to substitute in the equation, and rearranging terms, to get the relations

$$C/f = k - bf \qquad (2)$$

where k, b are constants

and $$C = kf - bf^2 \qquad (3)$$

From equation (2) it is clear that if the catch per unit effort is plotted against the effort, the result should be a straight line. Given suitable data, such a plot can be easily done, a straight line fitted, and the equilibrium relation between effort and catch per unit effort (and hence between effort and catch) is readily determined.

In practice it may take some time for the stock to react fully to changes in fishing effort. That is, the stock abundance in 1975 may be influenced as much by the fishing in 1974 as that in 1975 (and for long-lived fish the effort in 1973 and earlier years may also have an influence). The true equilibrium relation may therefore be given by plotting the catch per unit effort in 1975 against the average of the fishing effort in 1974 and 1975.

Another complication is that the true relations between catch, effort, and catch per unit effort may not be as simple as indicated in the equations above. In particular the relation between catch per unit effort and effort may not be linear. If so, this may appear when the plot is made. The easiest solution is then to draw the best fitting curve through the point by eye, from this curve the corresponding relation between catch and effort can easily be calculated. Alternatively, the relation between c.p.u.e. and effort may be best described (instead of equation 2) by the expression

$$\text{c.p.u.e.} = c/f = a^f$$

or $$\log (c/f) = f \log a$$

That is the plot of the logarithm of c.p.u.e. against effort should give a straight line.

In all these calculations three quantities (c, f, c/f) are considered, but only two are independent. Traditionally c and f are expected to be available from the statistics of fishery, and from them c/f can be directly calculated.

In practice there are few fisheries anywhere in the world - and even fewer in the developing world - for which the statistical systems are adequate to provide data on the total effort, and for which the fishery is sufficiently uniform for such statistics of total effort to be meaningful. For example a stock of pelagic fish may be exploited by modern purse seiners, gill-net vessels, and small, non-powered boats using a variety of gears. Effort data in terms of total number of vessels in this fishery does not mean much.

In such fisheries it is much better to use information from only a small group of ships, that are reasonably similar, in order to produce a figure of c/f. This can be used as an index of abundance of the population, and also to calculate the total effort, using the relation

$$f \text{ total} = \frac{C \text{ total}}{c/f}$$

In the extreme case, the estimate of c/f may be obtained from the catches of the research or survey vessel. (See Example 3). A possible disadvantage is that a survey vessel may not be able to make many hauls each year, so there may be a large degree of variation in each year's figure. Against this is the great advantage that the vessel and gear can be kept unchanged, so that there can be confidence that changes in the c.p.u.e. do reflect properly changes in stock abundance.

In any analysis of this type it is important that all the data refer to a single stock. Ideally this would be a self-contained population of a single species, but this is not always practicable where a hundred or more species are caught in a single fishery. In this situation all the species in a community, e.g., all the bottom living fish in a particular area may have to be treated as a single stock. This may be a reasonable procedure, and give reliable answers, provided that there are not too big differences between different parts of the stock, e.g., if fishing is concentrated in one part of the area. In that situation it may be necessary to sub-divide the area, and treat the demersal fish in each sub-area as separate stocks to be analysed independently. For example it may be desirable to treat separately the demersal fish in the Java Sea within 20 m (which seem to be heavily fished by the traditional fisheries), and outside 20 m (which are at present only lightly fished). The correctness of this procedure should be checked by Looking at, for example, the species composition to see to what extent there is interchange between the two "stocks".

Where effort data is used from part or all of the fishery itself, a careful examination should be made of ways in which the measures used can become unreliable. That is, ways in which the amount of fishing represented by one unit of effort (as recorded in the statistics) can change from year to year. Usually the effort data will be calculated as the sum of fishing effort by each of the vessels in the fishery, and the effort by each vessel will be given as the product of the fishing power of the vessel times, the time it spent fishing, or the number of operations, i.e.,

$$\text{Fishing effort of the fleet} = \sum \text{fishing power} \times \text{fishing time.}$$

At the simplest, the fishing power of all vessels may be taken as equal, and the measure of fishing time taken as the operations during one year. Then the fishing effort will be equal to the number of vessels operating (see Example 2). Clearly both these assumptions are likely to become invalid, at least over a period. New and more powerful vessels may enter the fishery, the efficiency of existing vessels may be increased by adding new equipment, etc. Equally, the amount of time spent fishing during the year may change - initially for various reasons boats may only fish for a few months during the year. The second point may be, in part, dealt with by using as a measure of fishing time a month operation, i.e. the fishing effort may be estimated as the sum of the number of vessels operating each month.

Even this measure could give an unreliable measure (apart from changes in the fishing power of the vessels), if there is a shift in the seasonal pattern of fishing, e.g., to more fishing at that time of the year when catches are particularly good. If there are marked differences in catch rates, and year-to-year changes in the seasonal pattern of fishing, then it may be desirable to calculate catch, effort, and catch per unit effort for each month separately. Then the best index of abundance, or c.p.u.e., for the year would be the average of the monthly c.p.u.e. The annual effort could then be derived by dividing this into the total annual catch.

The actual numbers obtained for effort and c.p.u.e. for a particular year using these various procedures are not of great significance in themselves for stock assessment purposes (though several effort units, e.g., number of vessels or number of fishermen are of relevance to other, economic and social purposes). Thus, it is not possible, with reference to one year, to say that one measure is not more correct, or more valid, than another. The important test is how well the figures of effort (or c.p.u.e.) measure changes in the amount of fishing (or stock abundance) from one year to another. If the fishing power of the ship does not stay constant, then a correction by the use of some factor, e.g., the average horse-

power, must be applied. Similarly, if more fishing is done, on the average, by each ship during the year, the catch per vessel per year may fail to show a decline in the stock, and a better measure of fishing time may have to be used. However, if these changes (in average fishing power, or average fishing time) do not occur, then there is no need to include these corrections. Since data collection and compilation should always be kept as simple as possible it may then be best to use the number of vessels as the measure of fishing effort.

3.2 Estimation of catch rates

Many surveys are more immediately concerned with the estimation of catch rates, i.e., what a fishing vessel operating commercially would catch per day at sea, or per year of operation. Even when the survey vessel has been working almost entirely with this objective in mind, that is the survey has been designed and carried out solely as a prospecting survey, the estimation procedure is not entirely straightforward. Unless the vessel operated strictly on commercial lines (and in that case the coverage of the survey area is likely to be poor), it may do less fishing per day at sea than the expected commercial average, and do it where the catch rates are less than the maximum attainable. The simple average of the catches per day, or catches per year may therefore under-estimate the catch rates that might be obtained by a commercial vessel. Also, while the vessel and gear used for a prospecting survey should always be close to those it is expected will be used by the commercial fishery, it is unlikely that they will be exactly the same, and this difference should be allowed for.

These problems may in part be dealt with, and also the data from resource appraisal surveys used (with caution) in estimating catch rates, by noting that the catches by any vessel are given by the product of its fishing power, multiplied by the time spent fishing (per day or per year) multiplied by the average density of fish at the positions at which fishing is done. Rather than attempting to compare catch rates between survey and commercial vessels directly, it is easier to consider differences in the individual factors.

Differences in fishing power have been studied extensively and for some gears are quite well understood, and for these, differences between survey and commercial vessels are readily allowed for. For example, the fishing power of bottom trawlers is nearly proportional to the size or power of the vessel, as measured by, for example, its gross tonnage, or engine horse-power. For gears consisting of a number of similar but distinct units, e.g., lines or traps, or even gill-nets, the fishing power is given by the numbers of lines or traps, or length of nets. For some gears catching pelagic fish matters are more complicated. For example mid-water trawls are usually not effective, and catch virtually no pelagic fish, unless they are above a certain size, or towed above a certain critical speed, depending on the behaviour of the fish. Above these limits catches tend to increase roughly in proportion to the size or power of the vessel, but if the ship is not big or powerful enough to tow a big enough net fast enough, she will catch little. Similarly a purse-seine has to be at least of a certain critical size, depending on the species, to be an efficient method of catching active pelagic fish. For these gears catches of survey vessels can be used with reasonable confidence to estimate catches by commercial vessels that are at least as large and powerful as the survey ships. Extrapolation of the survey data to smaller ships could, however, be misleading.

Corrections for differences in effective fishing time is straightforward, provided the records of the survey vessels are available in terms of, for example, hours trawling, and the likely amount of hours fishing by commercial vessels per day at sea, or per year can be estimated, e.g., from records of similar vessels operating in other areas (see Example 4).

Differences in the densities of fish at the fishing positions cause the greatest difficulties in interpretation. Clearly commercial vessels actively searching for the best grounds will work on higher densities than vessels making resource appraisal surveys and working at positions that are random with respect to fish density. They are also likely to work at higher densities than survey vessels even when the latter are prospecting and

looking for good concentrations of fish, since the commercial vessels will, as the fishery develops, have the benefit of accumulated experience of where and when the best catches are taken. It is common in the early stages of the development of a fishery for the catch rate (even of the same ships with the same captains) to increase for the first two or three years as the fishermen learn the best positions and techniques. This learning effect is believed to be of the order of a factor of three in some of the fisheries of the northwest Atlantic.

Clearly, however, there must be some relation between the catch rates of a survey vessel and the subsequent catches in a commercial fishery. This relation may be clearer in terms of the frequency distribution of catch rates (e.g., catch per haul). The distribution for a vessel carrying out resource appraisal surveys will reflect the full range of variation in the density of fish at different parts of the survey area. The commercial fleet will take a selection from the upper part of this range and the very low catches will seldom occur. However, there is no reason to suppose that the survey vessel will not occasionally be lucky and hit on the very high densities of fish. That is, the catch rates achieved in the one or two most successful hauls in a survey are probably at least as high as those that will be taken, on the average, by the commercial fleet. A first approximation to future commercial catch rates might therefore be to take, say, the average of the best 10 percent of the hauls made in a resource appraisal, or perhaps the best 50 percent made in a prospecting survey. These figures are of course arbitrary, but may give a guide that is more useful either than using the average overall hauls, or not taking advantage of the survey data at all. Alternatively, there is some evidence that where commercial fishing has followed a resource survey, the catch rates in the commercial fishery once it has become well established are some x times those in the survey, due allowance being made for differences in fishing power.

3.3 Estimation of stock abundance and potential yield

The analysis of resource appraisal data is usually aimed, in the first instance, at producing an estimate of total abundance (N), or mean density (d) in the survey region. As a first stage the actual survey data can be used to produce estimates of the abundance or density at the particular place where the surveys were made. These may be a number of distinct areas (e.g., the area covered by individual trawl hauls, or sampled by a single plankton net haul), or a zone along the track of the survey vessel (e.g., an acoustic or visual survey).

In either case we can write

a = areas sampled in the survey
A = total area surveyed
n = number (or abundance) in the area sampled

then N, the total numbers (or abundance) will be given by

$$N = n \times (A/a)$$

or, in terms of density

$$N = A \times \text{density} = A \times (n/a)$$

The important assumption is that the density in the sampled area is the same on the average as that in the survey area as a whole. This assumption will only be correct if the sampling is unbiased which requires careful survey planning.

Where individual samples (e.g., trawl hauls) are made, we can write:

$$a = \sum a_i$$

$$n = \sum n_i$$

where a_i, n_i are the areas covered, and number sampled at the individual stations (see Example 5 (i), and Examples 6 and 7).

For egg (or larval) surveys this procedure will provide estimates of the number of eggs (or larvae) present at the time the survey was carried out. In itself this figure is of little interest, and must be interpreted in some way to provide an idea of the fish stock. In principle, the numbers of eggs (or larvae) could either be projected forwards, to provide estimates of the number of fish of commercial size which would result from the spawning, or backwards, to determine how many adult females were needed to produce the observed quantity of eggs.

In practice the survival between the egg (or larval) stage and the youngest commercial size is too variable to enable a forward projection to give useful results. Despite the large number of studies made of fish eggs and larvae there are few instances of any clear relation between their observed abundance, and the subsequent abundance of commercial sizes of fish. On the other hand, the losses among eggs are commonly sufficiently small to enable estimates of egg abundance (or, less frequently, the abundance of very young fish larvae) to give useful estimates of the abundance of the parent stock.

To do this, the estimates of egg abundance must be used to estimate the total production of eggs during the spawning season (or during a year for fish with no clear spawning season) (see Example 8). The following equations can be used:

N_i = number of eggs present at the time of the survey
d^i = average time from egg laying to hatching

then

N_i/d = average daily production of eggs during and just preceding the survey

E = total egg production during the season (or year). This may be expressed as the average daily egg production (averaged over the different surveys), multiplied by the length of the spawning season (or 365 for a year). Alternatively, and better, it may be estimated as the area under the curve of average daily egg production, plotted against time

also $E = P.F.n$

where P = number of mature females
F = average number of eggs produced in each batch by an individual female
n = average number of batches of eggs produced each year, or each spawning season by an individual female.

From this P can be written

$$P = \frac{E}{F.n} = \frac{N_i \; D}{F.n.d}$$ where D = length of spawning season

Further, since weight is of more interest than numbers

$W = P.\bar{w}$ = total weight of mature females.
where $\bar{w}$ = average weight of the individual mature females.

Since the sex ratio in most fishes is about 1:1, this can be doubled to estimate the total weight of mature fishes. In these calculations the figure used for $\bar{w}$ should correspond to the figure of individual fecundity F, since this is usually very closely related to weight. If this is done the estimate of spawning biomass W is likely to be relatively unaffected by changes in the size composition of the spawning stock.

For several survey gears these methods of analysis cannot be used directly to give stock abundance. This may either be because the area sampled is known, but the records obtained do not measure the actual quantity of fish in the sample region, e.g., many acoustic surveys, or because the effective area sampled is not known, e.g., most fishing gears. Data from these surveys can still be analysed to provide an index of overall abundance in relative

terms, that can be often very useful in studying year to year changes in abundance. (See Example 7).

The figures of stock abundance, as so many tons of fish present in the survey area at a given time, is not in itself of particular interest to non-scientists. They are interested more in the potential yield, i.e., how much can be taken from the stock each year, on a sustained basis. This will be related to the standing stock, and also to the turnover rate. The quicker the latter, i.e., the shorter the life span of the individual fish, and the more rapidly the stock replaces itself, the greater the yield that can be taken from a given standing stock. A formula that has become generally accepted is

$$Y = 0.5\ M\ B_o$$

when Y = potential yield

M = natural mortality coefficient

B_o = unexploited standing stock

This may be extended to stocks that are moderately or lightly fished, in the form

$$Y = 0.5\ Z\ B^1$$

where Z = total mortality coefficient = $F + M$

B^1 = exploited standing stock

(see Example 9)

3.4 Presentation of results

Surveys are not carried out for the benefit of those actually making the surveys. They have therefore not served their purpose until the results are made available to the actual users (fishermen, fishing industry, administration, other scientists). Different users require different information, supplied at different times, and with different detail. They therefore need to be supplied with different types of reports. As well as ensuring that the contents of the reports are suited to the particular group of users, those responsible for surveys should ensure that the physical condition and appearance of the reports, and the numbers of copies and methods of distributing them are adequate so that most, if not all, of the potential users are aware of and read the relevant reports.

This may seem a minor matter, but too often the results of good survey work have not found their way to the office where they would be best used, and in effect these surveys have been largely wasted. The type of report includes on the one hand the results of the detailed analyses and estimation of standing stock and potential yield, prepared some time after the conclusion of the sea work, and on the other, simple charts showing the track of the vessel and principal observations, which can be prepared and distributed immediately the ship returns to port.

4. EXAMPLES

Example 1

Eighteen hauls were made during a trawl survey, and the following catches (in kg) were taken:

Hauls 1 - 6 :	200	440	600	640	700	800
7 - 12 :	900	1 020	1 600	1 920	20	10
13 - 18 :	340	400	720	40	100	160

Calculate the mean, variance and standard deviation of the catch per haul.

How many hauls would be needed if it were desired to estimate, at the 5 percent level of significance, the mean catch per haul (a) within 10 percent, (b) within 5 percent), and (c) within 1 percent?

Example 2

A research vessel made seven one-hour hauls in a particular sub-division of a survey area. At each haul the weight caught of each species was recorded. In 4 and 5 hauls respectively samples of 20 kg each of two species were measured (total length to the cm below). The results were as follows:

Haul number	1		2		3		4		5		6		7	
Species	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Catch (kg)	75	80	12	30	25	55	60	15	35	45	90	80	10	20
Length (cm)	number in sample													
10 -	3	17	-	20	13	-	1	-	-	15	1	17	-	5
11 -	10	36	-	48	30	-	7	-	-	40	3	35	-	40
12 -	20	58	-	60	60	-	20	-	-	55	10	70	-	75
13 -	35	67	-	75	75	-	40	-	-	76	15	68	-	77
14 -	40	50	-	40	53	-	45	-	-	55	20	78	-	53
15 -	38	45	-	35	40	-	35	-	-	43	35	32	-	42
16 -	30	32	-	10	27	-	30	-	-	27	35	2	-	7
17 -	20	10	-	2	15	-	25	-	-	8	28	1	-	1
18 -	25	2	-	-	3	-	10	-	-	1	17	-	-	-
19 -	10	-	-	-	1	-	15	-	-	-	15	-	-	-
20 -	3	-	-	-	-	-	5	-	-	-	10	-	-	-
	-	-	-	-	-	-	-	-	-	-	3	-	-	-

For each species estimate the total numbers caught in each length-group during each haul from which samples were taken. Hence estimate the total number caught, and the average numbers per haul. What is the average length of each species in the total catches?

How would these estimates be affected if wider length-grouping (2 cm or 5 cm) were used.

Example 3

The average catch rates during trawl surveys in the Gulf of Thailand, and the estimates of total demersal landings are given below:

Year	1961	1962	1963	1964	1965	1966	1967	1968	1969
Catch/hour (kg)	298	no data	250	226	179	131	115	106	103
Landings (000 tons)	123	151	228	372	393	449	525	784	767

Estimate the equivalent effort, i.e., the hours fishing that would have had to be done by the commercial fleet, if they had the same fishing power as the survey vessel. Hence estimate the relation between total catch and effort.

(Note: the 1962 catch/hour may be obtained by interpolation).

Example 4

A survey trawler of 250 gross tons has been working in the South China Sea. During a few days during each survey grid hauls were made at positions chosen by the captain as being the most promising for fish. Altogether 74 one-hour hauls were made during which 27 200 kg of fish were caught, 62 percent of which were of good marketable quality. What would be the expected annual catches of good marketable fish by a 100 gross ton trawler, assuming that it could average 18 fishing hours per day at sea, and 260 days at sea per year, and also that the catch rate is proportional to tonnage?

Example 5

If the trawl net used in the data of example 1 covered 40 ha per haul, and it is assumed that it caught 50 percent of all the fish in its path,

(i) what is the estimated density (in kg/ha) at each station?

(ii) if the total survey area was 6×10^6 ha, estimate the abundance of the total stock;

(iii) what other estimate could be obtained, if it were known that the first 10 stations were taken in depths from 0–20 m, the next 5 in depths 20–40 m, and the last three in depths over 40 m, and it is known that the area of the three depth zones are 1×10^6, 2×10^6 and 3×10^6 ha respectively?

(iv) what are the variances of these two estimates? How would the variance of the second estimate be altered if the optimum allocation between strata is used?

Example 6

(i) A survey was made in an area of 800 n mi x 100 n mi. A total distance of 500 n mi was covered by a research vessel which used sonar equipment. This equipment could detect all fish schools within 2 mi of the ship. Altogether 200 schools were detected. How many schools are there in the whole region?

Visual estimates were that the average school size was 16 tons. How many fish are there in the region?

(ii) A subsequent survey some months later, extended over a track of 400 n mi. More detailed records were kept, and the sonar records were classified according to the size of school, with the following results:

Large schools	30
Medium schools	150
Small schools	90

A purse-seine was used on a number of schools, with the following average catches (in tons):

	Anchovy	Mackerel	Sardine
Large schools	25	3	-
Medium schools	15	5	5
Small schools	-	3	2

If only half the fish in the large schools were caught, how many fish of each species were there in the region during the second survey?

Example 7

Echo-surveys were carried out during two successive seasons. The traces were grouped into four densities, and the area of each type was calculated. In one season the catch rates on different types of echo-trace were observed, with the following results:

Type of trace	Absent	Very scattered	Scattered	Dense	Very dense
Area of trace, year 1	10	30	35	20	5
Area of trace, year 2	5	25	30	25	15
Catch rate	0	1	2	4	6

What was the change in abundance between the two years?

Example 8

Regular plankton surveys, at two month intervals, gave the following estimates of the average number of anchovy eggs present during six surveys.

Date of survey	January 10–18	March 3–9	May 21–27	July 1–10	September 12–20	November 3–15
Numbers (10^9)	10	40	40	20	10	5

If an anchovy egg takes two days to hatch, how many eggs were produced during the year (ignoring losses prior to hatching)?

If the average female, immediately prior to spawning, contains 10,000 eggs, and spawns three times per year, how many mature females are there?

How are these estimates altered (a) if time to hatching is three days, and (b) if anchovies spawn four times per year?

Example 9

Using the data of example 5, estimate the potential annual yield from the area surveyed (at present virtually unexploited), assuming that the average natural mortality of the species caught is 1.0. What different estimates would be obtained if: (a) the natural mortality were 0.6, and (b) the trawl caught 75 percent of the fish in its path?

5. ANSWERS TO EXAMPLES

1. Mean = 589.44, variance = 282 805.56, standard deviation = 531.79
With 95% confidence, the mean can be estimated within 10% with 326 hauls, within 5% with 1302 hauls, and within 1% with 32 558 hauls.

2. The estimates for sampled hauls are:

	Species A	Species B
Total number caught:	2881.75	3935.00
Average number per haul:	720.44	787.00
Average length:	14.97	13.08

These estimates would not be affected by wider length intervals.

3. In thousands of hours' trawling, the equivalent efforts are:

1961	412.75	1966	3427.48
1962	551.09	1967	4565.22
1963	912.00	1968	7396.23
1964	1646.02	1969	7446.60
1965	2195.53		

4. At the survey vessel catch rate of .9116 kg/GRT-hour, the commercial vessel will catch 426 610 kg/year.

5. (i) The estimated average density of 29.47 kg/ha.
(ii) The simple estimate of total stock size is 176 830 mt.
(iii) The stratified estimate of total stock size is 88 900 mt.
(iv) The variance of the simple estimate is 1414×10^{12} (standard deviation 37 600 mt); the variance of the stratified estimate is 270×10^{12} (standard deviation 16 440 mt). By definition, optimum allocation of sampling effort would reduce the variance of the stratified estimate.

6. (i) The estimated number of schools is 16 000, containing 256 000 mt of fish.
(ii) The stock estimates are 375 000 mt of anchovy, 120 000 mt of mackerel, and 93 000 mt of sardine.

7. The index of abundance was 210 in the first year, 275 in the second.

8. It would require 126.60×10^{6} females to produce the observed eggs under the initial assumptions. An extra day for hatching would lower the estimate by a third, an extra spawning by a fourth.

9. Under the initial assumptions, the potential yield would be half the stratified estimate of original stock size, or 44 450 mt. The lower natural mortality rate reduces this estimate by two fifths; the higher proportion caught reduces it by a third.

6. READING LIST

1. GENERAL CONSIDERATIONS

Alverson, D.L. (Ed.), 1971 Manual of methods for fisheries resource survey and appraisal. Part 1. Survey and charting of fisheries resources. FAO Fish.Tech.Pap., (102):80 p.

Gulland, J.A., 1971 Science and fishery management. J.Cons.CIEM, 33(3):471-7

_____ (Ed.), 1971 The fish resources of the ocean. West Byfleet, Surrey, Fishing News (Books) Ltd., 255 p. Rev. ed. of FAO Fish.Tech.Pap., (97):425 p. (1970)

Holden, M.J. and D.F.S. Raitt (Eds.), 1974 Manual of fisheries science. Part 2. Methods of resource investigation and their application. FAO Fish.Tech.Pap., (115)Rev 1: 214 p.

Ricker, W.E. and E.P. Weeks (Eds.), 1973 FAO Technical Conference on fishery management and development. (Vancouver, February 13-23, 1973). J.Fish.Res.Board Can., 30(12) Part 2:1921-2537

Rothschild, B.J. (Ed.), 1973 World fisheries policy: multidisciplinary views. Seattle, Wash., University of Washington Press, 272 p.

2. IMPLEMENTATION

Choice of gear

Dahn, E., 1974 Neuere Entwicklungen auf dem Gebiet der Grossraumortung in der Fischerei (Recent development in the field of large area radiolocation in fisheries). Protok. Fischereitech., 13(61):182-93

FAO, Department of Fisheries, 1973 Notes on international classifications and definitions used in fishing fleet, fishing gear and fishing effort statistics. FAO Fish.Cir., (429):pag.var.

Forbes, S.T. and O. Nakken, (Eds.), 1972 Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO Man.Fish.Sci., (5):138 p.

Gulland, J.A., 1964 Symposium on the measurement of abundance of fish stocks. Rapp.P.-V.Reun. CIEM, 155:223 p.

Smith, P.E. (Ed.), Techniques for pelagic fish egg and larva surveys. FAO Fish.Tech.Pap., (in preparation)

Woods, E.G., W.H. Stevenson and W.F. Gandy, 1975 Airborne sensing - future in fisheries. In Oceanology International 75, 16-21 March, 1975, Brighton, England. Sponsored by the Society for Underwater Technology. London, BPS Exhibitions Ltd., pp.202-6

Statistics and sampling

Bazigos, G.P., 1974 Applied fishery statistics. FAO Fish.Tech.Pap., (135):164 p.

Gulland, J.A., 1966 Manual of sampling and statistical methods for fisheries biology. Part 1. Sampling methods. FAO Man.Fish.Sci., (3):87 p.

Survey design and data recording

Mackett, D.J., 1973 Manual of methods for fisheries resource survey and appraisal. Part 3. Standard methods and techniques for demersal fisheries resource surveys. FAO Fish.Tech.Pap., (124):38 p.

Midttun, L., et al., 1972 Plan for pelagic fish assessment survey, North Arabian Sea. Rome, FAO, IOFC/DEV/72/25:23 p.

Regional Fishery Survey and Development Project. Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates, Report of the Ad hoc Working Group on survey technique and strategy. Rome and Doha, 15-26 September, 1975. Rome, FAO, REM/71/278/1. (In preparation)

3. INTERPRETATION

Alverson, D.L. and W.T. Pereyra, 1969 Demersal fish explorations in the northeastern Pacific Ocean - an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J.Fish.Res.Board Can., 26(8):1985-2001

Gulland, J.A., 1969 Manual of methods for fish stock assessment. Part 1. Fish population analysis. FAO Man.Fish.Sci., (4):154 p.

Ricker, W.E., 1975 Computation and interpretation of biological statistics of fish populations. Bull.Fish.Res.Board Can., (191):382 p.

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